Pre-cast Concrete in Blast Resistant Construction

By

Mark O. Whitney
Darrell D. Barker
Johnny H. Waclawczyk, Jr

Defense Department Explosives Safety Board Seminar

Abstract

Traditional concrete blast resistant structures are poured-in-place construction. Modem conventional buildings are often pre-cast construction due to economy of time and in some cases labor costs. The questions is, can pre-cast construction be appropriate for blast resistant facilities? The answer is yes, particularly in far range design. Buildings located at barricaded intraline distance out to inhabited building distance are all candidates for pre-cast concrete construction. These distances correspond to (K9 $W^{1/3}$) and (K40 $W^{1/3}$) which are at 12 psi and 1.2 psi respectively. At K9 charge quantities of 1,000 lbs or less and at K40 charge quantities of 100,000 lbs or less are applicable limits. In this paper we review pre-cast construction, describing different approaches taken in past designs and identifying loads which should be addressed during analysis. Particular attention is given in the paper to connection details and requirements. Connection design is an important aspect in blast resistant pre-cast construction. The topics of shear wall analysis and building overturing are also addressed. It is the conclusion of this paper that pre-cast construction is a viable alternative for blast resistant facilities. Also, pre-cast construction for blast design is not dissimilar from conventional type buildings, except that heavier member sizes and improved connection details are called out.

1.0 PRE-CAST CONSTRUCTION

Pre-cast construction has applications for blast resistant structures. In particular pre-cast construction is well suited for the far-range design. This includes buildings sited as close as barricaded intraline distance (K9) and as far away as inhabited building distance (K40). At these distances blast pressures are approximately 12 psi and 1.2 psi respectively. At K9 charge quantities of 1,000 lbs or less and at K40 charge quantities of 100,000 lbs or less are applicable limits. Pre-cast construction should be considered when it is advantageous for schedule or construction space constraints limit access for poured-in-place construction. Blast resistant pre-cast construction resembles conventional construction except that member sizes and connections are generally heavier than what are found in conventional buildings Pre-cast concrete construction provides protection of building occupants from hazardous missiles and debris generated at donor sites. This type to construction is preferred above other conventional approaches such as pre-engineered buildings or structural steel frame buildings with metal panel or masonry exteriors. This paper is limited to panels with conventional rebar and does not address the use of high strength tendons used in prestressed elements.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 1994**	2. REPORT TYPE	3. DATES COVERED **00-00-1994 to 00-00-1994**
4. TITLE AND SUBTITLE **Pre-cast Concrete in Blast Resistant Construction**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Wilfred Baker Engineering Inc,8700 Crownhill Blvd,San Antonio,TX,78209**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES **See also ADM000767. Proceedings of the Twenty-Sixth DoD Explosives Safety Seminar Held in Miami, FL on 16-18 August 1994.**		
14. ABSTRACT **see report**		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**17**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

1.1 Panels

Panels typically used in pre-cast construction include flat symmetric panels and nonsymmetric panels. Flat symmetric panels most often used as wall panels can be of single layer or double layer reinforcement. Double layer reinforcement is required for slab thicknesses greater than 10 inches while single layer reinforcement may be used for slab of thickness 10 inches or less. Determination of panel thickness and reinforcement requirements are based on the blast loads present. Thicker panels provide additional mass which resist blast loading through inertia response and resists overturning; however, this increase the total weight of the panels, some what increasing the labor involved in placement. For a given blast load, the greater the mass of a panel the less the reinforcement requirements are for that panel. Choosing a panel that is too thin may result in the inability of the concrete section to carry diagonal tension shears. It has been our observation that economical sections are chosen based on providing adequate concrete thickness to carry diagonal tension shears developed by the resistance of the panel. Often this results in a thicker panel with minimal reinforcing such that applied shears are minimized, adequate concrete section properties are provided, and stirrups are not required.

Non-symmetric panels, such as double T and single T sections, can be used in blast resistant construction. Such elements typically provide large section modules. Their use should be made in consideration of diagonal tension shears capacities and rebound capacity. Often web thicknesses must be increased over that typically specified for conventional construction in order for concrete sections to carry the diagonal tension shear that is developed by the ultimate resistance of the element. Non-symmetric panels do not have the same resistance capacity in rebound as they do in inbound motion under load. Rebound places the small portion of the section into compression. It has been our experience that over reinforcement (75% of balanced condition) is often exceeded and must be checked. Flat symmetric panels are preferred over non-symmetric panels for these reasons.

1.2 Connections

Prevention of connection failure in pre-cast construction is critical. Pre-cast construction does not offer the redundancy that cast-in-place construction provides. Connections are the most likely location for failures. Hence, pre-cast construction for blast resistant design calls improved connection details over conventional details. Most often connections will be simple type connections rather than fixed or moment carrying connections. This results in fairly flexible panels. Connection design loads are based on member reactions. In making connection load predictions, conservative calculations should be made to determine member end reactions. Often, member responses are made using conservative resistance-deflection function predictions; however, this would result in unconservative reaction load calculations. It is necessary to make separate calculations of member ultimate resistances such that conservative predictions of support reactions are provided. These calculations are made separate from resistance-deflection function calculations for flexural response calculations. Once conservative member reaction predictions are made, we recommend increasing these by an additional 10% based on recommendations in TM5-1300.

Connections should be designed to ensure that ductile mechanisms are evoked if connections attempt to pull out or tear away from the panels. Where tension loads are present we recommend the use of developed anchored reinforcement bars. For shear loads, studs may be used. We detail developed bar

anchors with hooks bending about a perpendicular-placed reinforcement bar. If rebar are welded to embedment plates, specify ASTM A706 Grade 60 rebar which is a weldable grade material. Ensure that the weld size is adequate such that tension would cause yielding in the rebar before loss of strength in the weld. As an alternative consider using mechanical connections, such as Cadwelds® to connect rebar to the anchor plates. Embedded anchor bars with hooks ensure that concrete pull out does not occur as would be present with studs alone. Such detailing results in ductile mechanisms in connection responses should load exceed those that are predicted. This is particularly important when the magnitude of the blast loads are uncertain. Most often, a conservative prediction of the maximum credible event is made and defined loads will not be exceeded. However, in situations when the explosive yield is unknown and a true definition of the maximum credible event is uncertain, then the potential for blast loads to exceed predicted loads is present. Excessive blast loads may not result in flexural failures of components but may result in excessive connection loads. Ductile type connections allow some redundancy and prevent brittle pull out of the connections from the concrete.

2.0 PRE-CAST PANELS WITH STEEL FRAMES

One approach of pre-cast construction is to utilize steel frames which are provided to support vertical blast loads applied to the roof. Pre-cast panels are placed on the exterior walls to resist lateral or horizontal blast loads. Wall panels are placed exterior to the frame and may either be connected directly to frame members or may simply lap the frame with connection between panels and tie-backs at columns. Figure l is a detail which we have used in the past for connecting panels directly to steel frames. Panels are cast with a structural WT perimeter form. Weldable rebar is attached to this perimeter form and are lap spliced with reinforcement placed interior to the panel. The structural WT provides convenient form which can be attached to a flat surface when the panels are poured. These panels would be bolted in place to the steel frame. Bolt holes are provided in the shop along with web stiffeners as necessary. The panels are lifted and placed against the frame, bolt holes marked against the frame, then the panel taken down. Field drilling of marked locations for matching holes on the frame are then provided. the panel is then lifted again to the frame and bolted in place.

The steel frame will support vertical blast loads and dead load of the roof. Lateral loads are resisted by walls supported by a roof diaphragm which transfer these loads to shear walls. If moment connections are provided in the frame, this adds redundancy to blast resistance. As mentioned, a feature that is lost in pre-cast construction compared to poured-in-place construction is redundancy of load transfer; hence moment connections on frames are recommended as they are economically provided.

Figure 1. Wall Panel-Column Connection

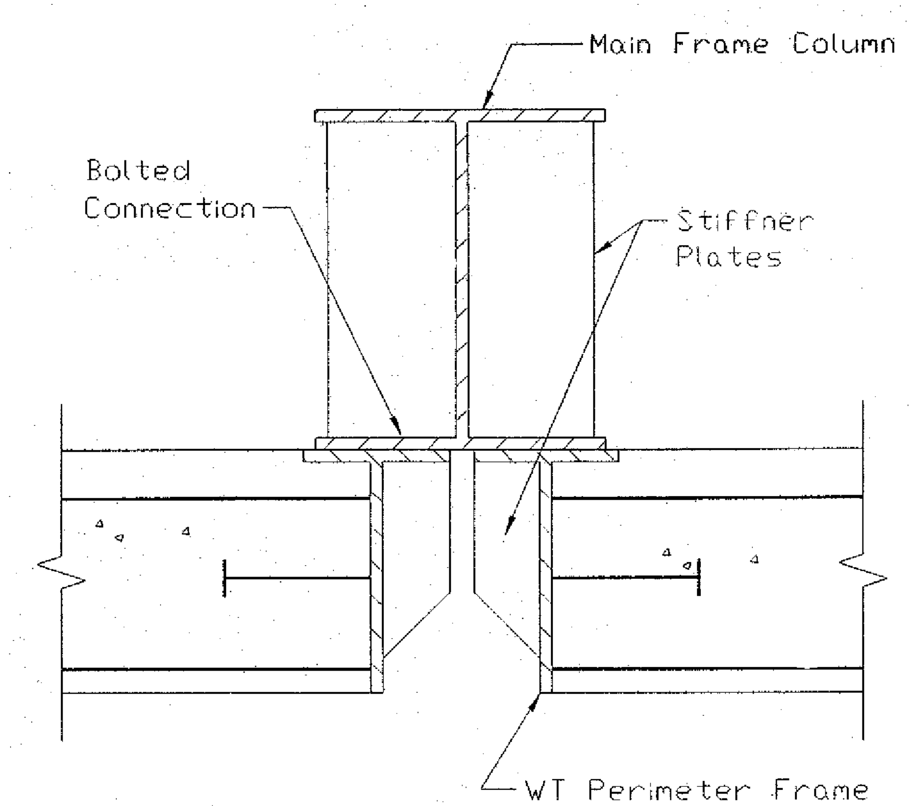


Figure 1. Wall Panel-Column Connection

A particular consideration for pre-cast construction utilizing steel frames involves rebound of the frames. When steel frames reach their maximum rebound deflection and begin to move once again towards the neutral position, panels will tend to separate from the frame producing high tension loads in the bolted connections. This situation is exaggerated should frame rebound timing be in phase with rebound response of the panel and/or negative phase loading from the blast wave.

Use of a diaphragm roof requires shear connections between the roof slab and the wall panels. If pre-cast panels are utilized for the roof as well as the wall, then connections must be adequate to transfer the shear loads. Also, a topping slab can be placed to provide the monolithic action for the diaphragm roof. One approach to providing shear transfer between the roof and wall panels include placement of mechanical connections in the wall panels as demonstrated in Figure 2. A hooked reinforcement bar is placed in the wall panel with mechanical connection at the surface. In the field, a reinforcement dowel is attached to the mechanical connection extending into the roof. The roof is then poured in place.

Most often diaphragm roofs are poured-in-place construction and pre-cast panels are not used. This is a horizontal concrete pour which can be constructed fairly cheaply compared to the cost of casting and placement of pre-cast panels. This is not true for walls, where the economy of pre-cast panels is desirable compared to the cost of vertical pours in cast-in-place construction. Cast-in-place roofs are commonly

accomplished on top of a metal decking which serves as a bottom form. The same detail for providing shear transfer between walls and the roof as discussed previously can be utilized. Quite often, a composite action between the roof beam and roof slab is used to stiffen the roof and reduce static deflections which lead to ponding. If so, consider this composite action when calculating end reactions.

Figure 2. Shear Connection Between Wall and Roof

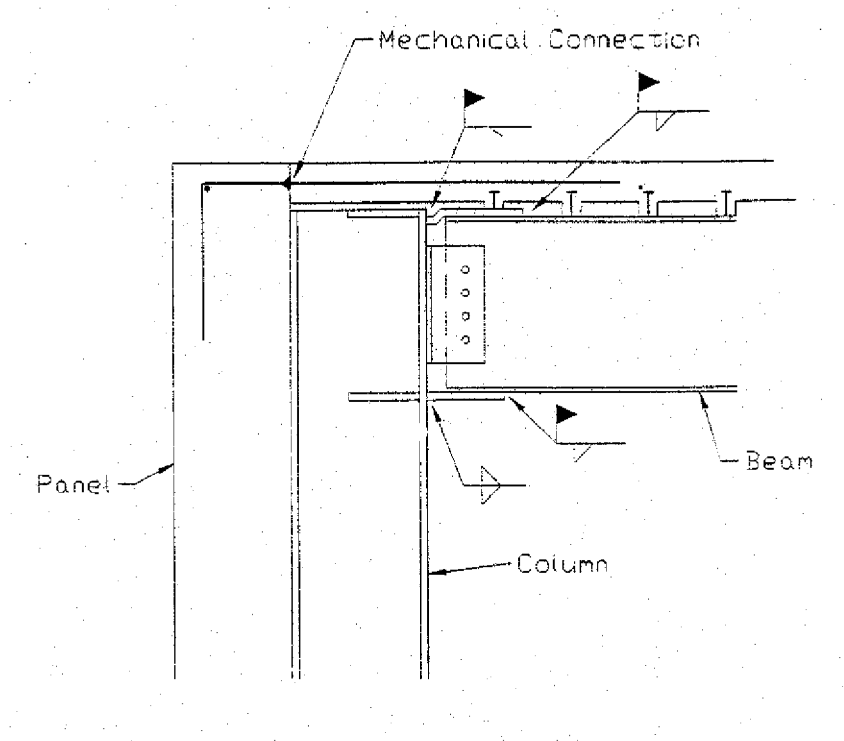


Figure 2. Shear Connection Between Wall and Roof

Panels placed exterior to the frame need not be secured directly to the frame member as described previously. Panel to panel connections can be provided directly with simple connections at the top and bottom of each frame. One option of panel to panel connection is to provide dowel extensions from the panels of embedment length and cast-in-place a section of wall between two adjoining panels, this provides a continuous exterior wall.

Panels on shear walls can be used to resist lateral loads. Panel connections to frames must address panel action as a shear wall. Cross-bracing between columns can be added to support shear wall action.

3.0 LOAD BEARING WALL PANELS

Pre-cast buildings can also be constructed without the use of interior steel frames. The exterior walls are load bearing and will carry both vertical and horizontal loads that are applied to the building. Roof beams are connected to wall panels at embeds placed at the top of the panels. Walls are tilted into place

and restrained, roof beams are placed and connected, then a diaphragm roof is poured. Walls are connected to the foundation at embeds provided in wall panels and the floor slab. Figure 3 illustrates a roof framing plan where beams are connected to wall panels at embeds. Notice that the panel width and beam spacing are selected such that a repeated pattern of embed location on the panels is provided. This greatly simplifies detailing and design efforts.

Figure 3. Roof Framing Plan

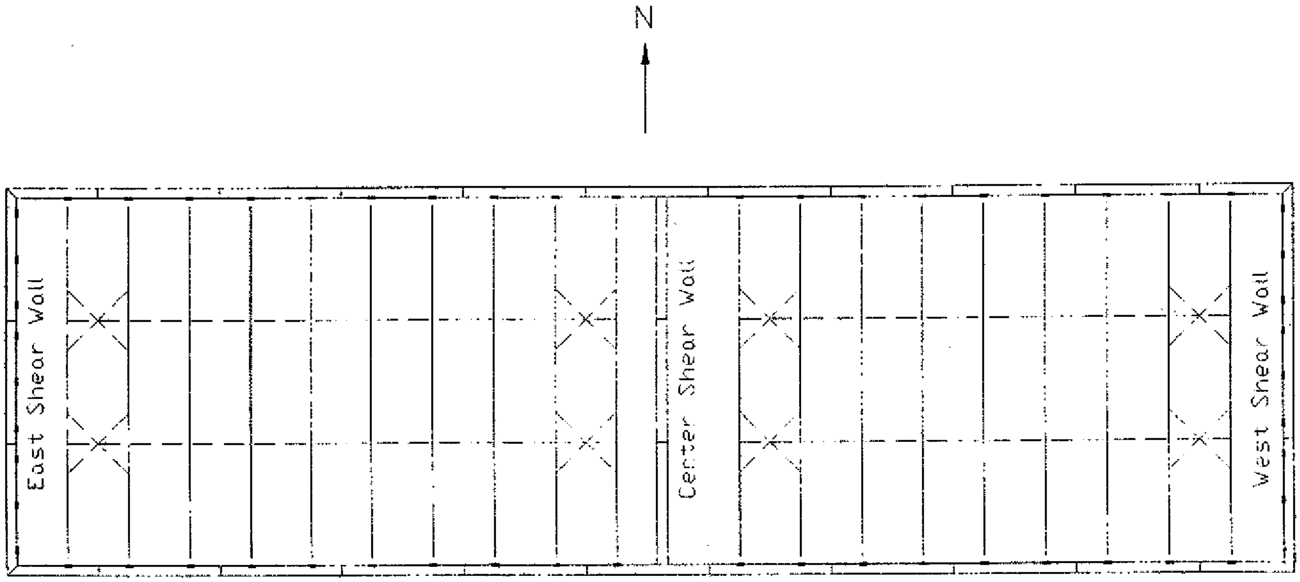


Figure 3. Roof Framing Plan

3.1 Forces on Load Bearing Panels

Load bearing wall panels must resist several load combinations which are present at the same time while loads that the panels must resist are not present at the same time. The following are loads which panels must resist.

1. Directly applied lateral blast loads.
2. Diaphragm reactions.
3. Vertical loads including roof beam reactions and dead loads.
4. Panel rebound forces.
5. Tension from overturing.

When a pre-cast building is orientated with one exposure face-on to the blast source that exposure will receive reflected loads which are of much greater magnitude than the side walls will receive. If the structure is oriented such that quartering loads are received at two faces, then lateral response in both directions will be experienced by the building. As a single panel responds in flexure, panels on

adjacent sides will also be responding in flexure. Assuming that their natural periods are approximately the same and considering that diaphragm action is fairly stiff, the panels will see this flexural response at the same time it must behave as a shear wall. Also, at the same time the blast wave will sweep across the roof providing a vertical load.

Should the roof beams natural period be similar to that of the wall then the wall will receive end reactions from the roof beams due to the blast load. This will be in addition to the dead load that the walls will be supporting. If the walls are designed for large deflections then this vertical loading will induce additional moments reducing the capacity of the wall. Thus, the wall must deal with several forces that can occur at the same time and designs must account for these load combinations. In addition, attention must be given to panel rebound to ensure that adequate connections are provided. Finally the gross structural motion of the building can, as it tries to overturn, result in tension forces present in the wall panels to prevent uplift of the building, which are transferred to the foundation through connections.

3.2 Connections

As mentioned previously we wish to provide connection details that are designed to safely handle any applied loads or load combinations. Also the connections are designed such that ductile response is present should the capacity be exceeded. Most often panels are connected through the use of embedded steel plates with field welding provided. Load combinations that the connections may see include reactions due to member flexural response, member rebound, shear forces, and tension forces.

Pre-cast panel walls that must behave as shear walls may be considered either as non-composite walls or composite walls. As non-composite walls, slip between panels is tolerated and the sum of the individual panel capacities must be adequate to provide resistance to transfer diaphragm roof loads. In many cases these loads are well in excess of the capacities of the panels acting in a non-composite fashion. To develop composite action between panels, connections must be adequate to prevent shear slip along the plate. For substantial lateral loads this may result in numerous plate connections between two panels. Often a continuous connection is a viable alternative. In situations where lateral loads are excessive, the use of panels at end-walls to resist these loads may not be adequate. In these situations end-walls may be poured-in-place construction while the lateral loaded walls can be remain panels.

Detailing of connections should include placement of anchored reinforcement bars. We recommend that these bars be placed such that their development length is provided in the compression face of the section. Avoid tension face placement of rebar anchors.

Figures 4 through 11 are typical of connection encountered in pre-cast construction and which we have used in the past for blast resistant construction.

Figure 4. Roof to Exterior Wall Connection

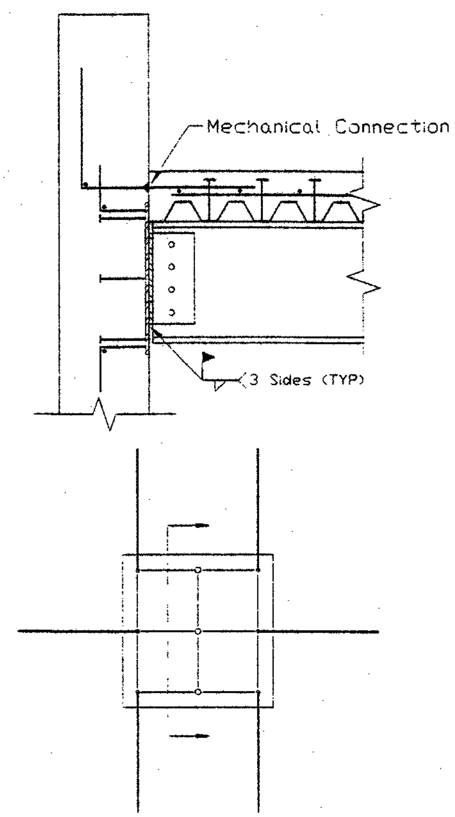


Figure 4. Roof to Exterior Wall Connection

Figure 5. Typical Panel to Panel Connection

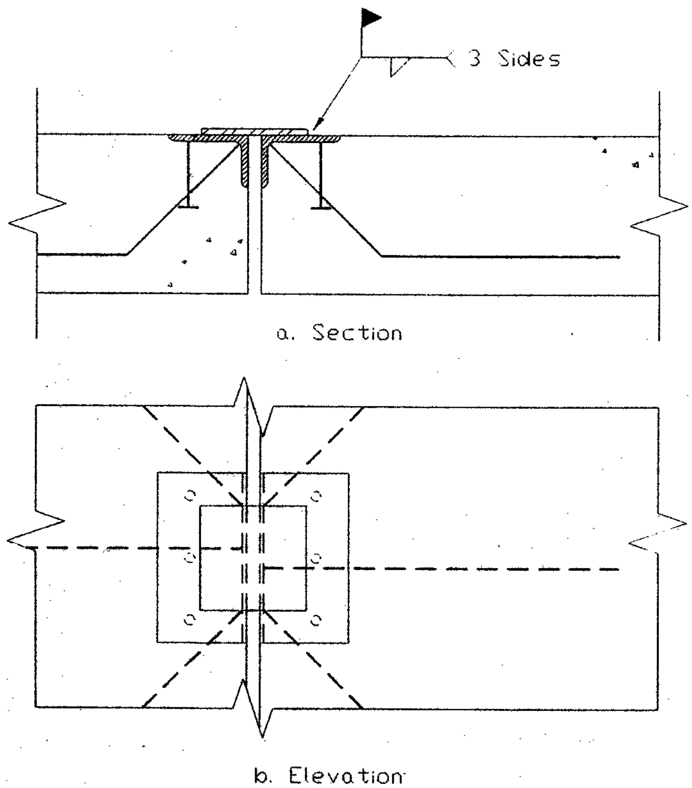


Figure 5. Typical Panel to Panel Connection

Figure 6. Wall to Wall Connection at Corner

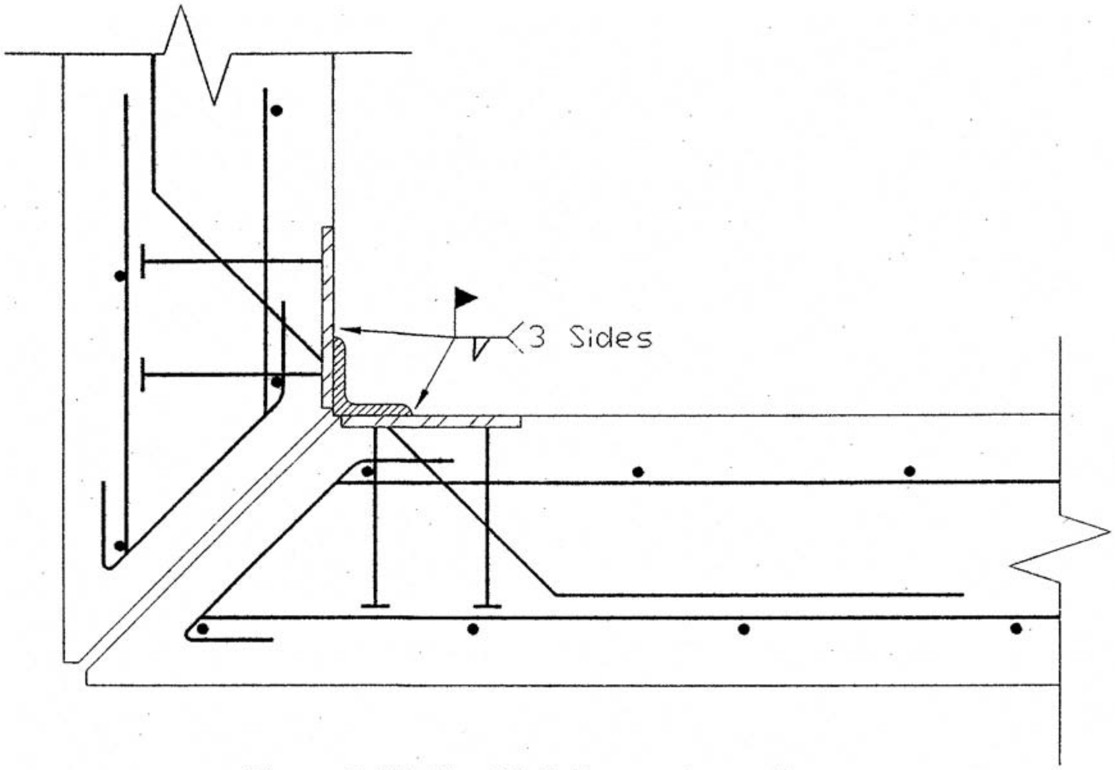


Figure 6. Wall to Wall Connection at Corner

Figure 7. Center Wall to Wall Connection, or Wall Connection, or Fixed Connection at Exterior Wall

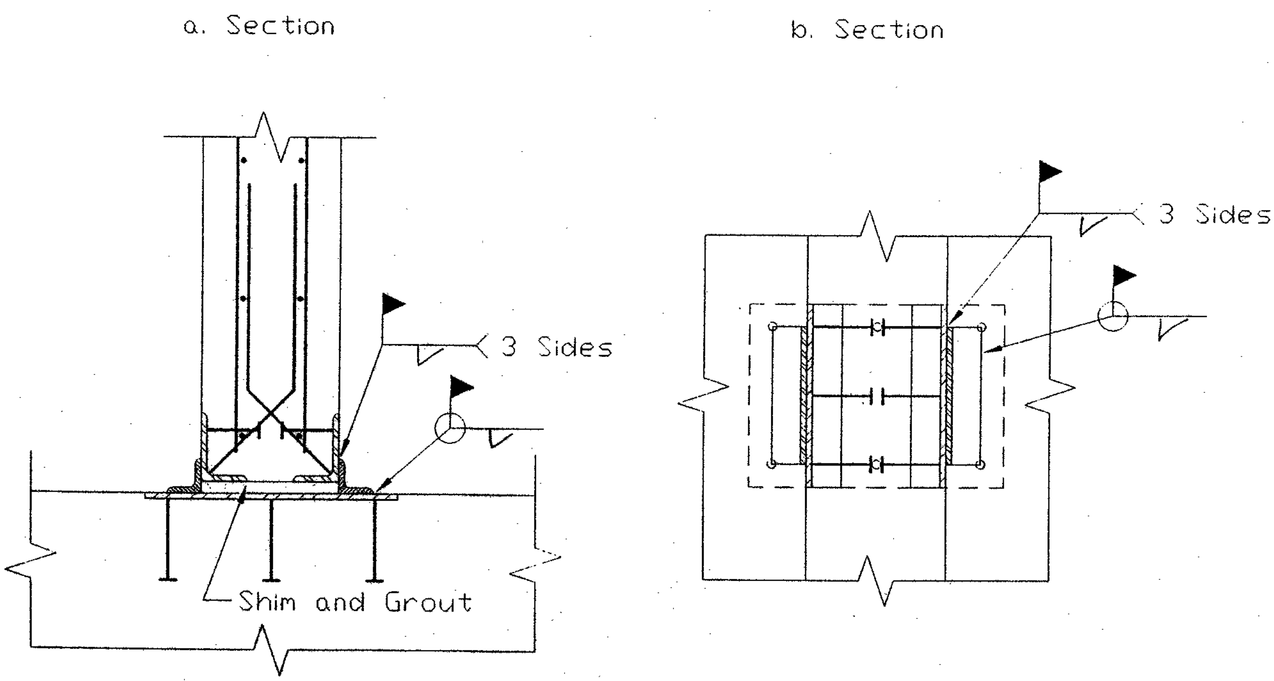


Figure 7. Center Wall to Wall Connection, Floor or Wall Connection, or Fixed Connection at Exterior Wall

Figure 8. Center Wall to Roof Connection

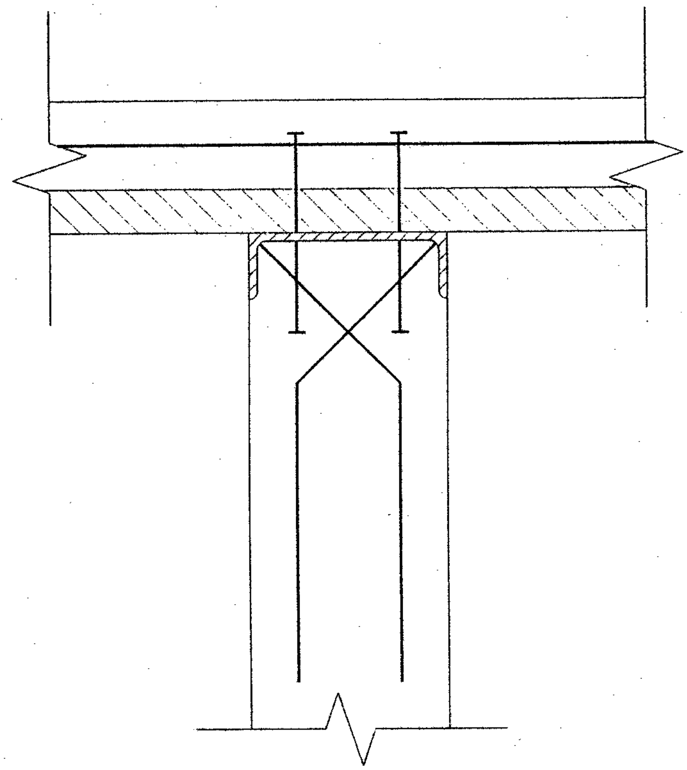


Figure 8. Center Wall to Roof Connection

Figure 9. Wall to Floor Connection

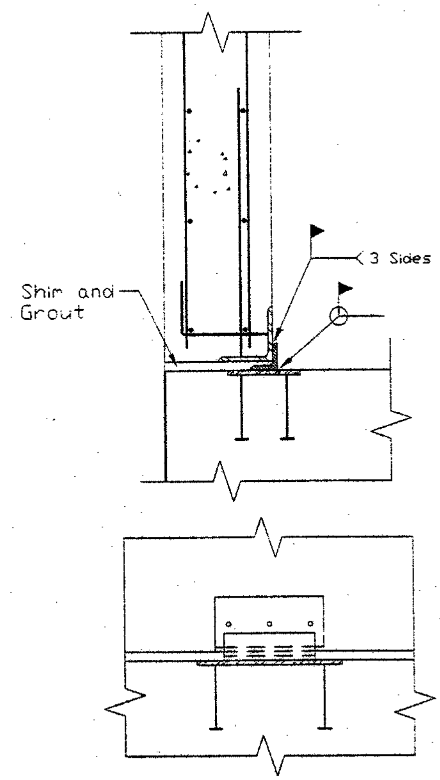
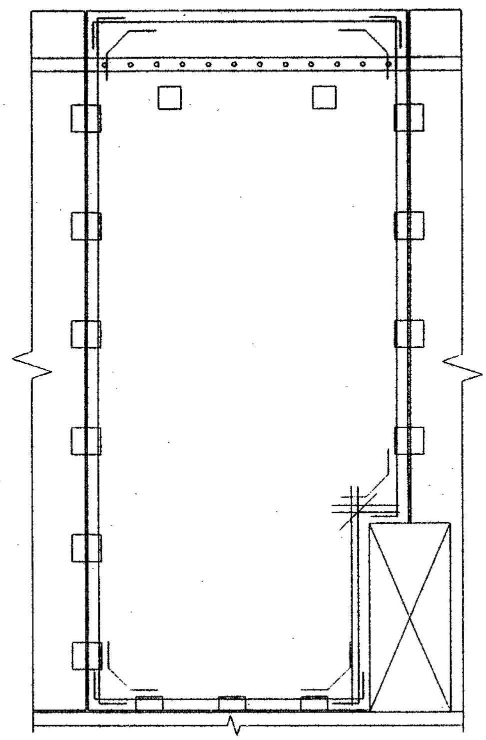


Figure 9. Wall to Floor Connection

Figure 10. Panel with Door Penetration



Fiugre 10. Panel with Door Penetration

- Figure 4 illustrates wall to roof connection. Diaphragm shear is transferred by dowels at mechanical connections. The roof beam is a simple connection. The wall embed plate is connected with a combination of hooked bars and studs.

- Figure 5 is a panel to panel connection. Bars are developed into the slab at the compression face. Studs are also provided for shear. Figure 6 is a typical panel to panel connection of similar attributes.

- Figure 7 is typical of several details. This could be a center wall to wall connection or a floor to interior wall connection. Also, if a moment connection is desired this detail will suffice. However, we recommend that a continuous connection with skip welds be provided such that the connection strength far exceeds wall moment capacity. Also, we recommend that the lap splice of bars take place well above the negative hinge, again to assure a dependable hinge be formed in the panel and not connection failure.

- Figure 8 illustrates a center shear wall to roof connection where studs are used to transfer shear loads.

- Figure 9 is a typical exterior panel to floor connection. The horizontal dowel prevents diagonal tension shear failure on rebound.

- Figure l0 is typical of panel to panel connections. Note that many more connections are required for blast than is common in conventional construction. In some cases, continuous connections can be employed. We recommend placement of openings at edges of panels, as shown, with the opening split between two panels. This allows for maximum panel width and locations for connections.

4.0 SHEAR WALLS

Shear walls must resist diaphragm reactions which transfer the flexural response of lateral loaded walls. The load that reaches a shear wall has changed from that of the pressure-time history of the blast load. To determine shear wall loading, first the flexural response of the lateral loaded panels is determined along with its end reactions. These end reactions are then applied to the diaphragm responding as a deep beam. Subsequently, the end reactions of the diaphragm roof are then calculated. These end reactions are then applied to the shear wall to determine its response. Thus, shear walls receive a "filtered" load compared to that of the blast load history. If the negative phase of the blast wave can be determined with confidence, and because responses of the building are slow compared to most time histories, then the overall response of the building can be reduced by considering this negative phase loading.

Figure 11 illustrates a wall consisting of 3 panels connected to react as a composite section. Some load cases may require continuous connections be provided between panels. For even greater loads, consider poured-in-place shear walls.

Figure 11. Multiple Connection for Composite Shear Wall Action

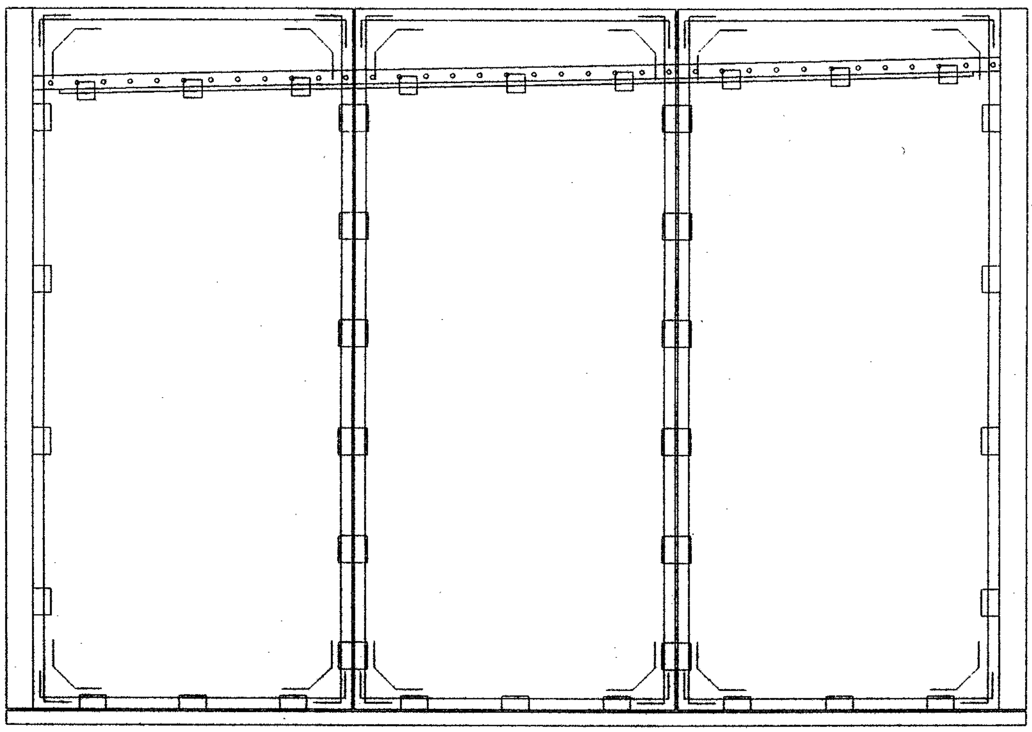


Figure 11. Multiple Connection for Composite Shear Wall Action

5.0 Overturning

Connections between panels and between panels and roof slabs provide for a unit behavior in the building. A simple approach for overturning analysis would consider the reflected face loading only and that backside loading is set to zero. The dead weight of the building plus vertical blast loads resist overturning while the reflected lateral loads induces overturning. Moment calculations are made as a quick check to determine if overturing will take place. If so, single-degree-of-freedom approximation of overturning can be made to determine if this is excessive. A detailed approach to overturning considers loading on the front face and the back face of the building. The time phasing between the application of these loads is considered. Also, negative phase loads should be considered if they can be calculated with accuracy. If back face loading occurs quickly before overturning response has been completed then this load serves to reduce the total overturing response. In some situations, however, the application of back face loads and negative phase loading may enhance the possibility of overturning upon rebound of the structure. A second order effect which may be considered is the rebound response of the roof. If rebound of the roof is in phase with overturning of the building then this may enhance the potential of overturning.

Overturning analysis results in a definition of tension loads at wall panel connections with the foundation. Wall panel connections should be adequate to resist these tension loads and transfer the load into the foundation. This will enact the dead weight of the foundation which in most cases is

adequate to prevent overturning. Presence of piers or bell footings also work to prevent overturing.

6.0 SUMMARY

It is the conclusion of this paper that pre-cast construction is suited for blast resistant design and is applicable for far-range loading. In particular between distances of unbarricaded intraline distance out to inhabited building distance pre-cast construction has its application (depending on the charge quantities involved). In general the pre-cast construction to blast resistant design is similar to that of conventional structures except that heavier sections and improved connections are provided. The greatest difference between conventional and blast resistant pre-cast construction is in the connections which are greatly improved for the enhanced loads. Particular attention and design must be paid to prevent connection failures. Also, the design of pre-cast construction should consider the building responses such as transferred shear wall loads and overturning of equal importance to component responses. Often in blast resistance design, considerable attention is paid to determining flexural response of individual components. For these types of buildings, gross building response should be equally investigated in design.